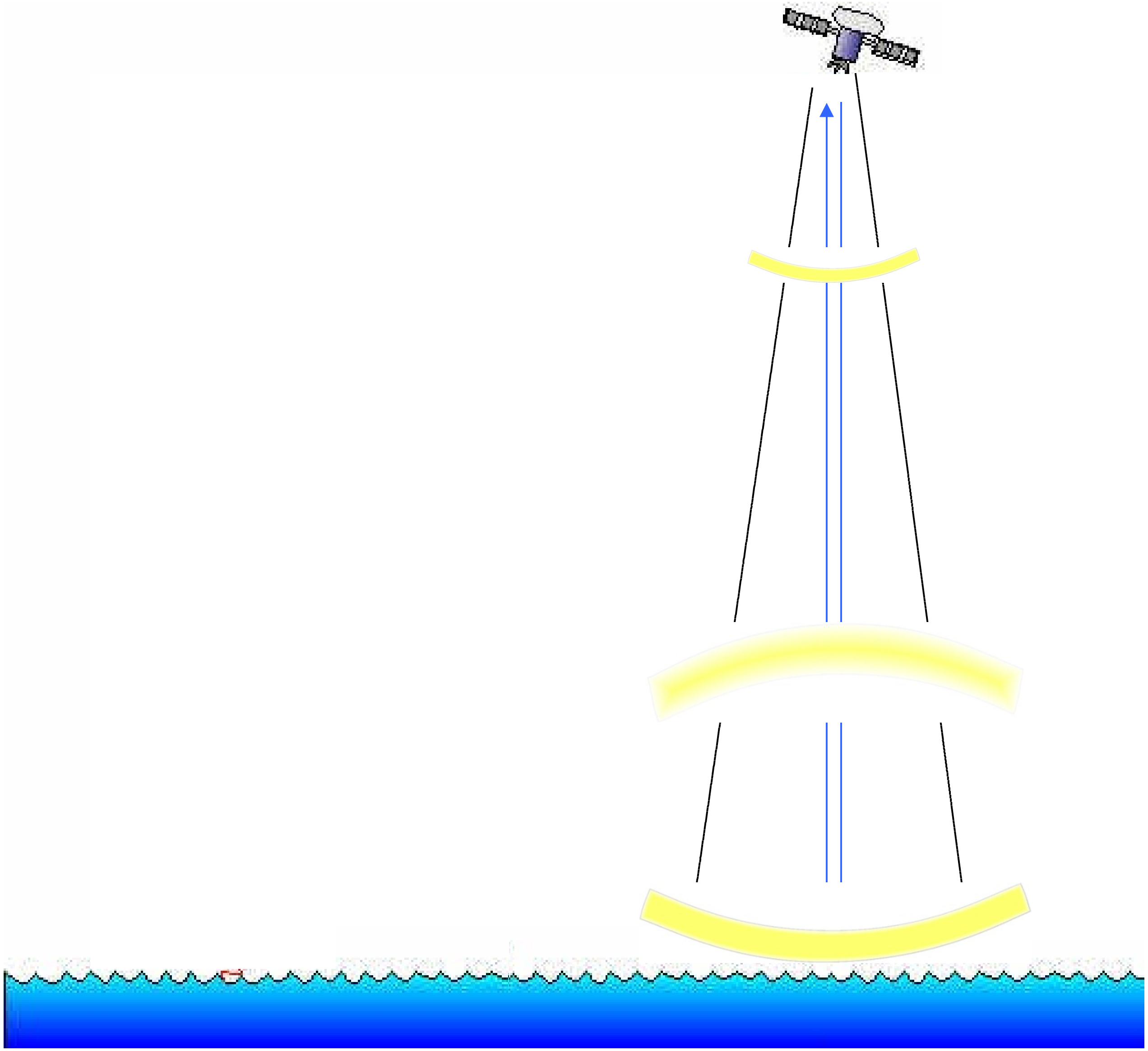
Active Microwave Radar



Two concepts behind active radar measurements:

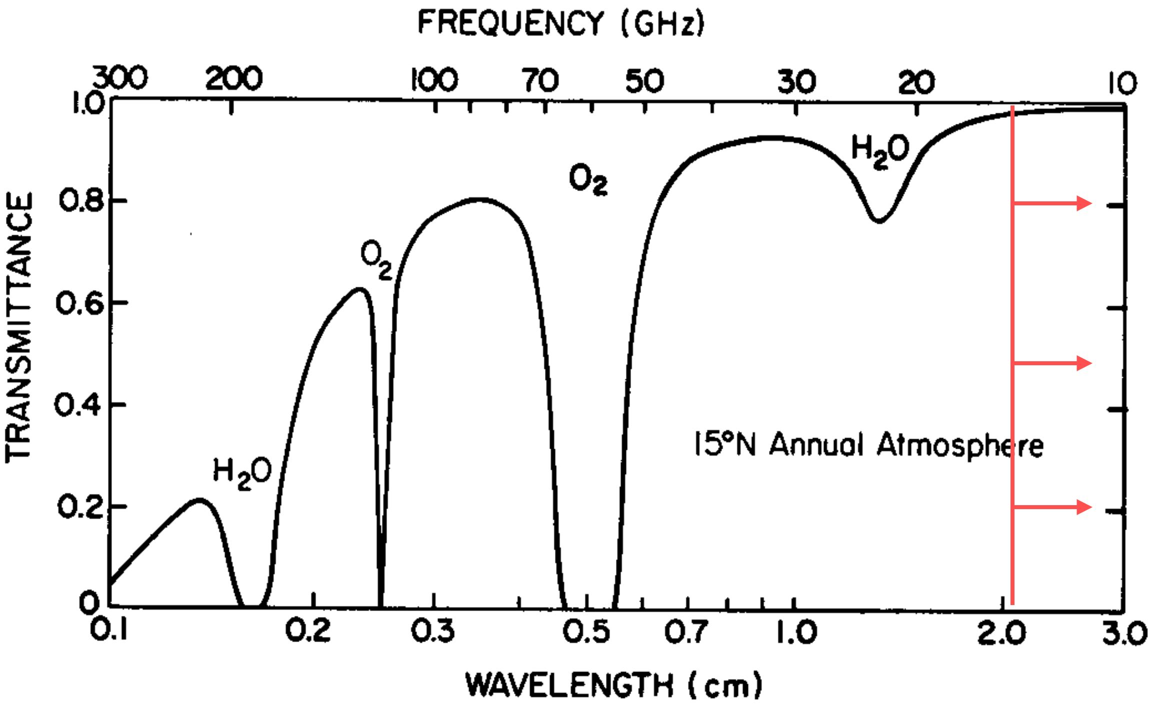
RADAR ===> RAdio Detection and Ranging

1. Use the roughness of a surface and how it scatters energy at a specified μwave frequency to infer either the characteristics of the surface or the characteristics of the forces that are modifying the surface.

2. Use time delay of radar send/receive signals to measure the distance between sender and the surface.

Radars are “active” remote sensors in that they transmit photons into the atmosphere and measure those that get scattered back to the sate

Satellite based radars are designed to detected physical characteristics of the surface or atmosphere.



Since they are not usually interested in the gaseous constituents of the atmosphere, they typicall operate at frequencies below 15 GHz to improve transmittance

Radiative Transfer Equation

$$L_t(\lambda,\Theta,\Phi) = L_0(\lambda,\Theta,\Phi)e^{-\tau(\lambda)/\cos\theta} + \int_0^{\tau(\lambda)} \frac{\kappa_a B(\lambda,T)}{\kappa_e} e^{-\tau(\lambda,z)/\cos\theta} \frac{d\tau}{\cos\theta} + \int_0^{\tau(\lambda)} \frac{\int_{4\pi} \beta_s(r,r',\lambda,X)L(r',\lambda,X)d\Omega}{\kappa_e(\lambda,z)} e^{-\tau(\lambda,z)/\cos\theta} \frac{d\tau}{\cos\theta}$$

$$\boxed{\Phi = L \int_{Area} dA \int_{\Omega} d\Omega} \quad \& \quad \boxed{L = \Delta\Phi / (\Delta\Omega \Delta A \cos\Theta)}$$

For Active Radar - 2 parts to Φ

$$\Phi_R = \boxed{\Phi'_\sigma} + \boxed{\Phi_{TN}}$$

$$where\ \Phi_{TN} = \Phi_{Noise} + \Phi_{Background}$$

Antenna details:

Define power pattern of antenna

$$R(\Omega) = \int_A \int_{\Delta f} L_f \, dA \, df$$ Radiant Intensity Watts/Sr

$$\Phi = \int_\Omega R(\Omega) d\Omega$$ Watts

$$P(\Omega) = \frac{R(\Omega)}{R_{\max}(\Omega)} = = \frac{R(\Omega)}{R_{\max}(0^o)}$$ 0 degrees defined as “boresight”

Antenna Gain defined as:

$$G(\Omega) = \frac{4\pi R(\Omega)}{\int_\Omega R(\Omega) d\Omega} = \frac{4\pi R(\Omega)}{\Phi}$$

If antenna is isotrophic (same characteristics overall) then $R(\Omega) = R_0$,

$$\Phi_0 = \frac{G_0 \Phi_T}{4\pi}$$

$$\Phi_{RS} = \frac{\Phi_T G_0 A_T}{4\pi R_0^2}$$

$$\frac{\Phi_{\text{Receiver}}}{\Phi_{\text{transmitted}}} = [\frac{G_0}{4\pi R_0^2}][A_T (1 - f_A) G_{TS}][\frac{A}{4\pi R_0^2}]$$

Proportional to the transmitted power measured at target

Target properties

Proportional to power received at receiver (satellite)

$$\boxed{\sigma = A_T(1 - f_A)G_{TS}}$$

$$\frac{\Phi_{\mathrm{Receiver}}}{\Phi_{\mathrm{transmitted}}} = [\frac{G_0 A}{(4\pi)^2 R_0^4}]\sigma$$

$$\& \text{ if } G_0 = 4\pi A / \lambda^2$$

then

$$\boxed{\sigma = \frac{\Phi_{\mathrm{transmitted}}}{\Phi_{\mathrm{Receiver}}} \frac{(4\pi)^3 R_0^4}{G_0 \lambda^2}}$$

$$\frac{\Phi_{\mathrm{Receiver}}}{\Phi_{\mathrm{transmitted}}} = \frac{\lambda^2}{(4\pi)^3} \int_{Afov} \frac{G_0{}^2 A}{R_0^4} \sigma_0 \, dA_s$$

$$\frac{\Phi_{\text{Receiver}}}{\Phi_{\text{transmitted}}} = \frac{\lambda^2}{(4\pi)^3 R_0^4} \int_{Afov} A \frac{G(\theta,\phi)^2}{R_0^4} \sigma_0 dA$$

and for a narrow beam: $G(\theta,\phi) = G_0, R_0 \sim \text{constant}$

$$\boxed{\sigma_0 = \frac{\Phi_{\text{Receiver}}}{\Phi_{\text{transmitted}}} \frac{(4\pi)^3 R_0^4}{G_0^2 \lambda^2 \Delta A}}$$

$$\sigma_0 = \frac{\Phi_{\text{Receiver}}}{\Phi_{\text{transmitted}}} \frac{(4\pi)^3 R_0^4}{G_0^2 \lambda^2 \Delta A}$$

Sigma Nought (σ_0)

"…a normalized dimensionless number, comparing the strength observed to that expected from an area of one square meter. Sigma nought is defined with respect to the nominally horizontal plane, and in general has a significant variation with incidence angle, wavelength, and polarization, as well as with properties of the scattering surface itself."

(From Canadian Centre for Remote Sensing Glossary)

Radar Equation

in symbols and words

$$\Phi_{Receiver} = \Phi_{Transmit}\left[\frac{G_0}{(4\pi)R^2}\right]\sigma\left[\frac{A}{(4\pi)R_0^2}\right]$$

Received Power = Radiant intensity (W/m²) incident on the target

*

Radar Scattering Cross-section of the target

*

Fraction of the scattered power recieved by the radar

Φ_T = Transmitted power

G_T = Gain of transmission

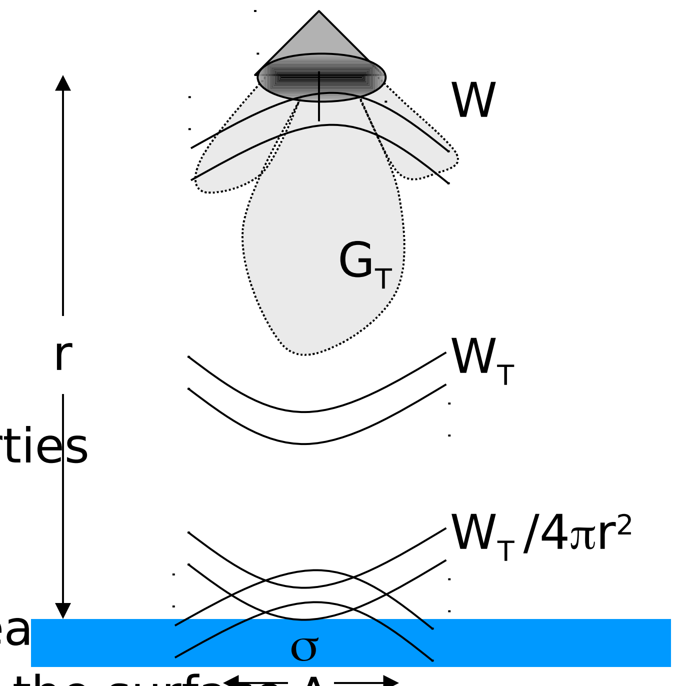
A_{eff} = effective receiver area of the antenna

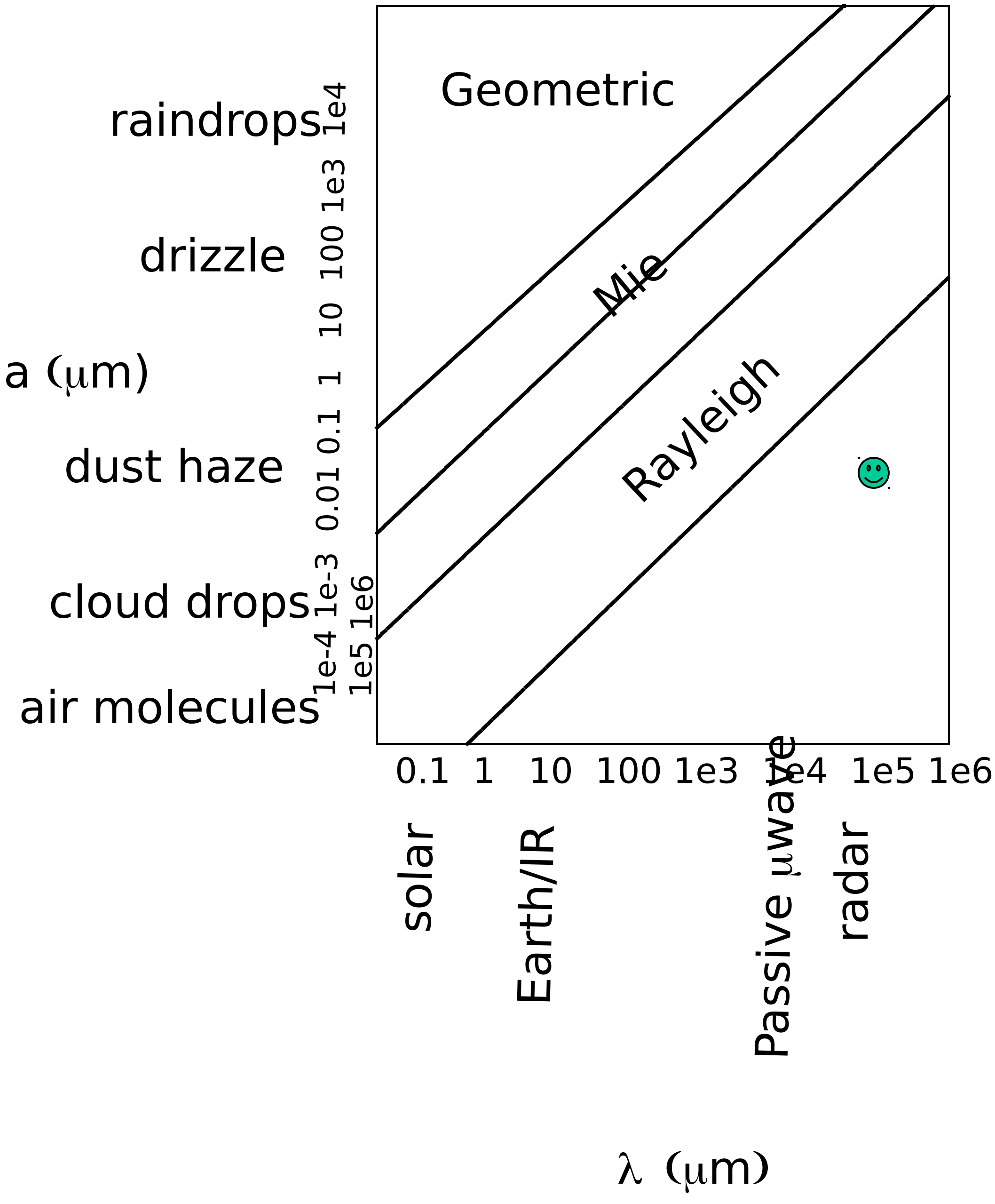
$$\Phi_{Receiver} = \Phi_{Transmitted}\left[\frac{G_0 A}{(4\pi)^2 R^4}\right]\sigma$$

σ is the link to the surface properties

$$\sigma = \int_A \sigma_0 \, dA$$

σ_o is the dimensionless cross-section/area depends on scattering characteristics of the surface



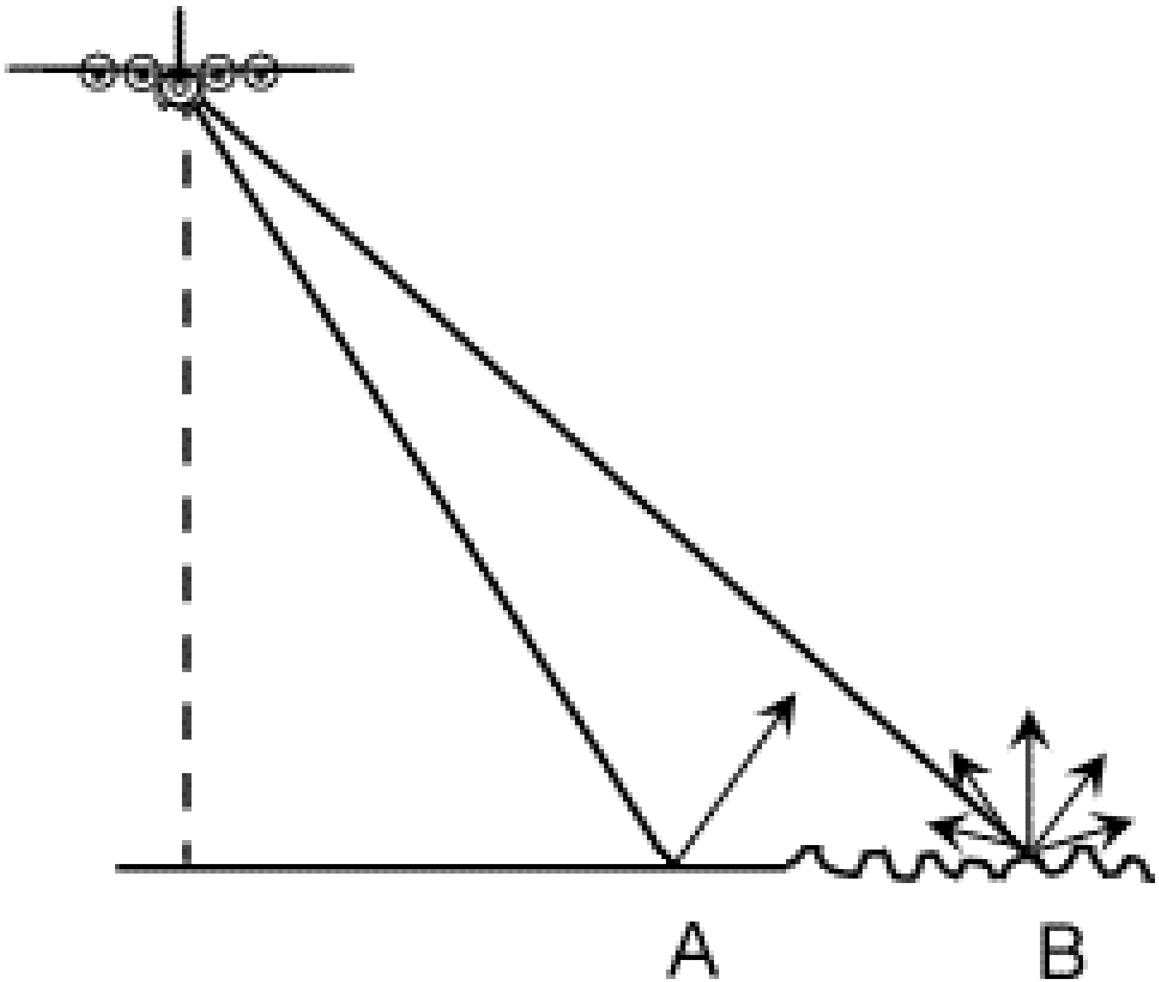


Geometric
Mie
Rayleigh
raindrops
drizzle
a (μm)
dust haze
cloud drops
air molecules
1e4
1e3
100
10
1
0.1
0.01
1e-3
1e-4
1e6
1e5
0.1
1
10
100
1e3
1e4
1e5
1e6
solar
Earth/IR
Passive μwave
radar
λ (μm)

We use a the μwave frequency that interacts with the small scale capillary waves.

And the type of scattering is referred to as Bragg scattering.

Reflection difference between rough and smooth surface

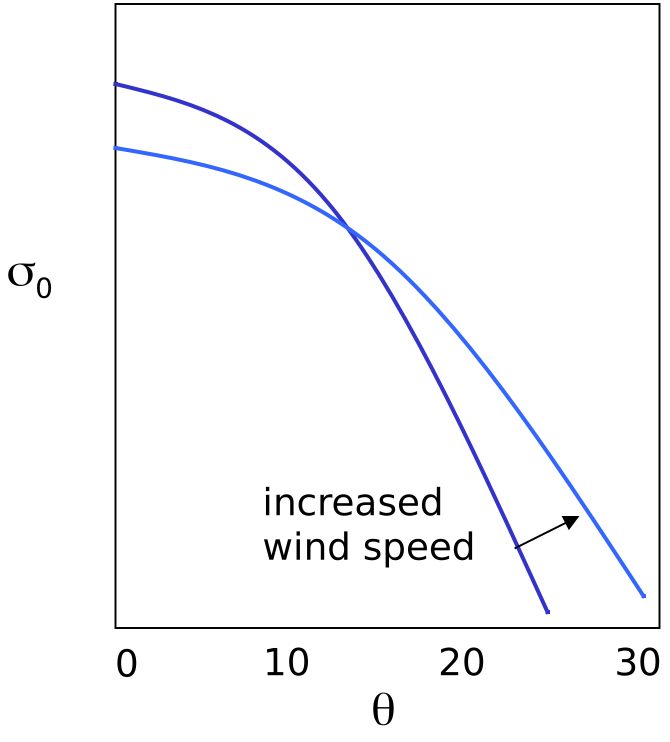


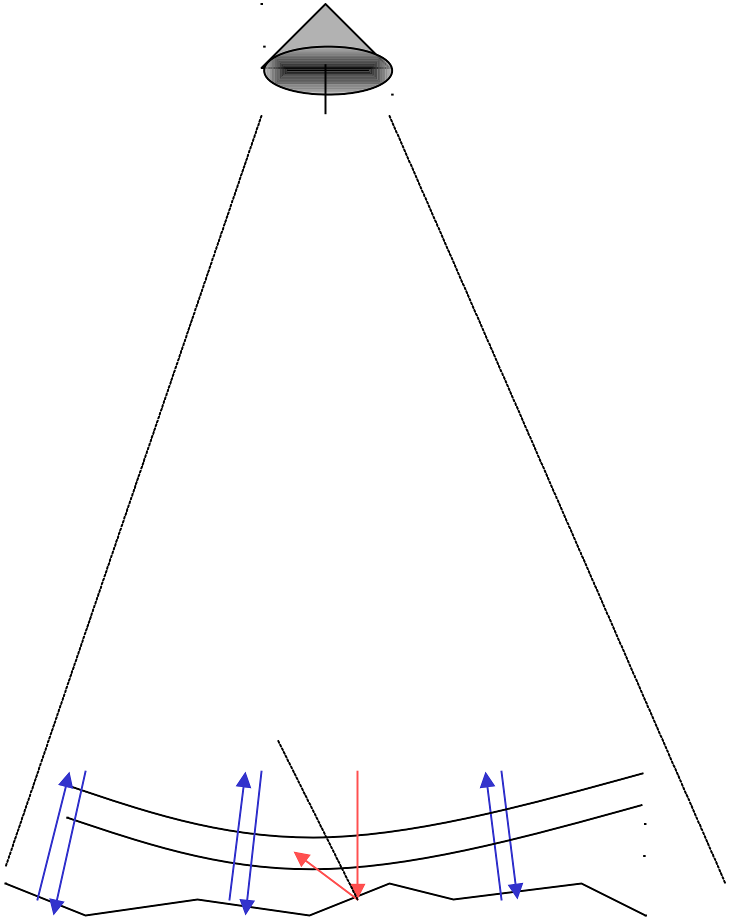
Scattering cross Section, σ_o

(1) Specular Reflection

Near vertical incidence

reflection off mirror-like facets





Important for θ < 20° (there are almost no wave slopes > 25°)

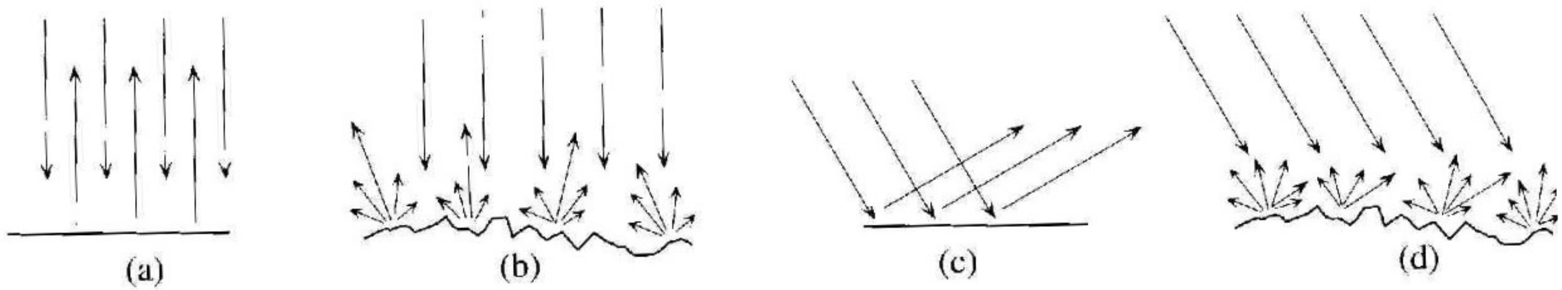


Figure 10.13. The specular reflection and incoherent scattering of a radiance incident on a surface. (a) Normal incidence, specular surface; (b) normal incidence, wave-covered surface; (c) oblique incidence, specular surface; (d) oblique incidence, wave-covered surface. See text for further description.

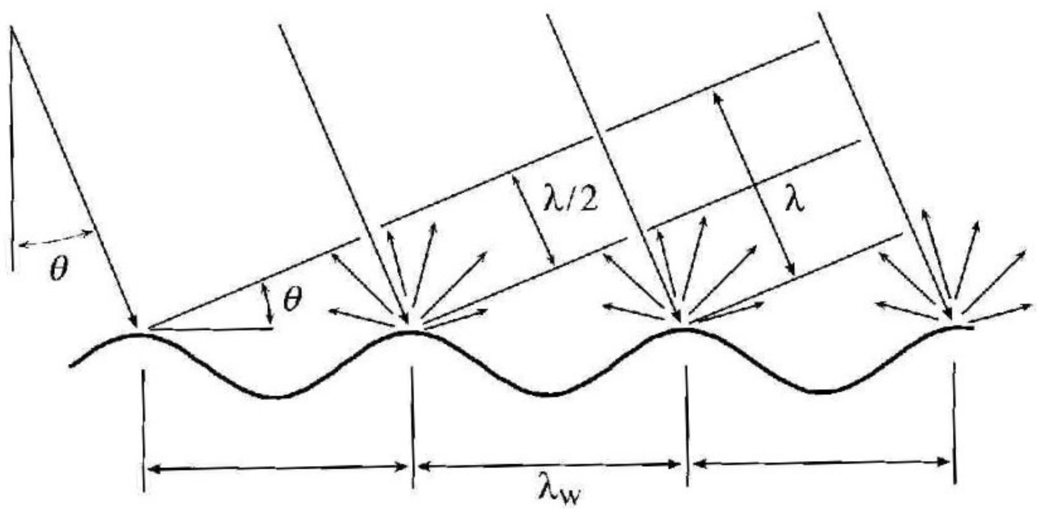
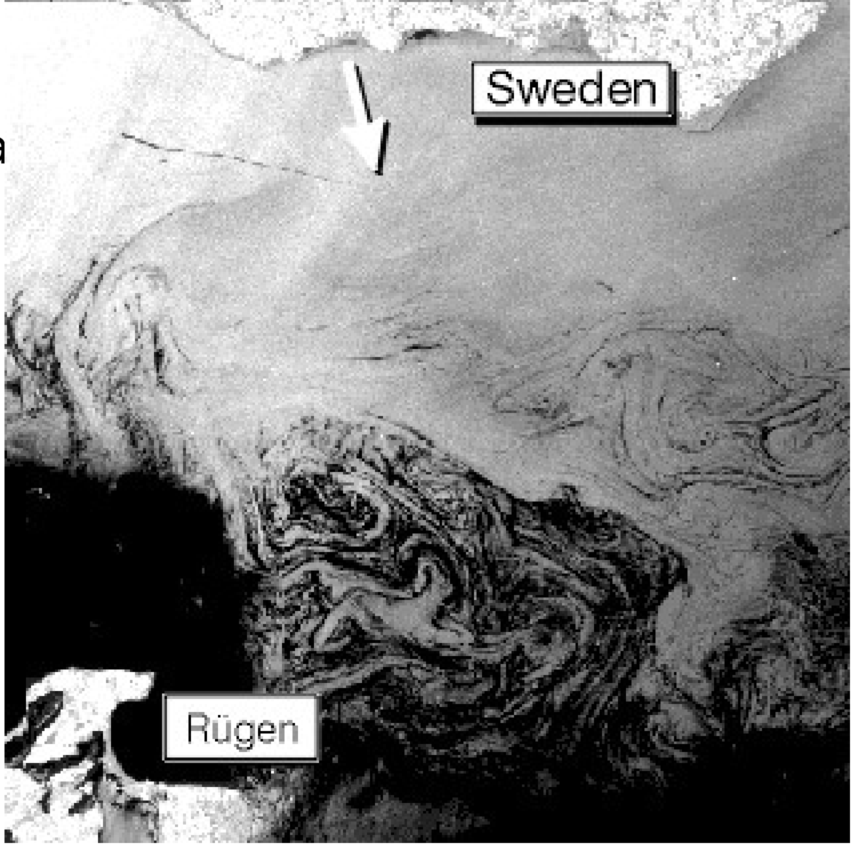


Figure 10.14. A schematic drawing of Bragg scatter modeled after the ERS-1 SAR. For the numbers given in the text, $\lambda_w = 72$ mm. See text for further description.

Bragg (resonant) scattering

active radars: spectrum of sea surface wa

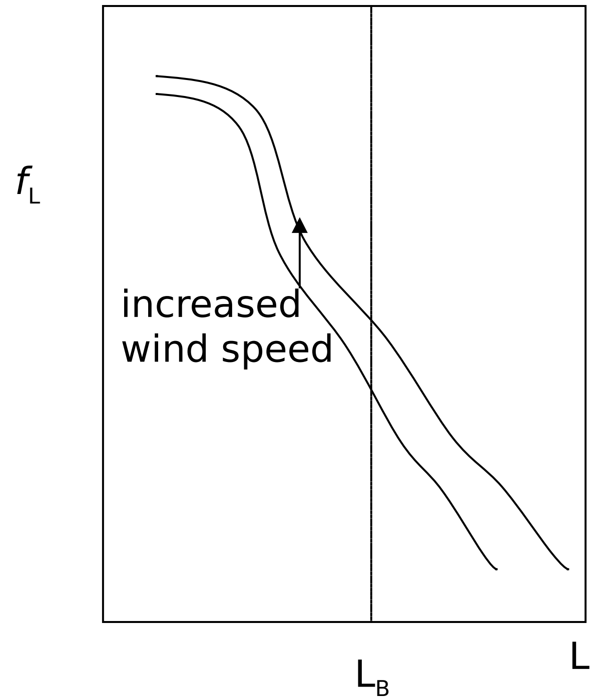


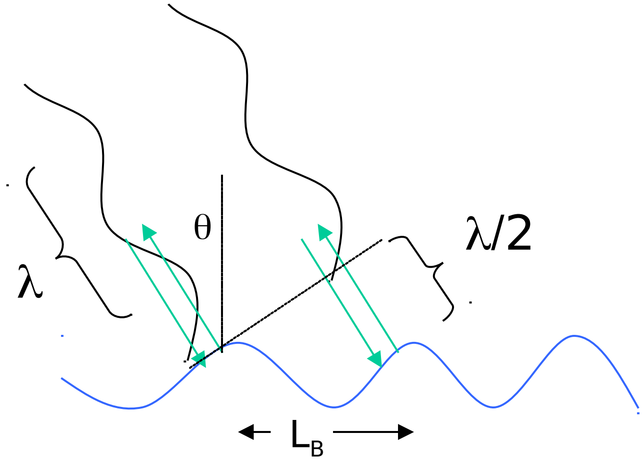
In the incidence angle range between 20° and 70° the main mechanism for the backscattering of microwaves from the ocean surface is described by Bragg
scattering theory [20]. The power of the backscattered radar signal is therefore dependent on the spectral power density of water surface waves, which depends on the radar wavelength and the incidence angle. The radar wavelength of the ERS-1/2 SAR = **5.7 cm** and the (mean) incidence angle = 23 °, the corresponding Bragg wavelength, is **7.2 cm**.

In Figure 1 a composite of two ERS-1 SAR images acquired on April 16, 1994, at 21:04 UTC over the southern part of the Baltic Sea is shown (image dimensions 100 km by 100 km). The dark, spiral-like signatures in the bottom half (Pomeranian Bay) are very likely caused by natural surface films which have
been formed on the water surface due to high biological activity in that particular coastal region in April (spring plankton bloom). The shape of biogenic slicks mostly occurring in coastal waters is caused by interactions with surface currents and eddies. The large, completely dark areas, e.g., north off the island of Rügen, could be caused by surface films or by low wind speed (below the threshold value for wave generation). Note the dark elongated line in the upper left part (south off Sweden) which is very likely caused by mineral oil freshly spilled out from a ship (the bright spot on the right edge of the spill, see the arrow).

(2) Resonant (Bragg) Scatter

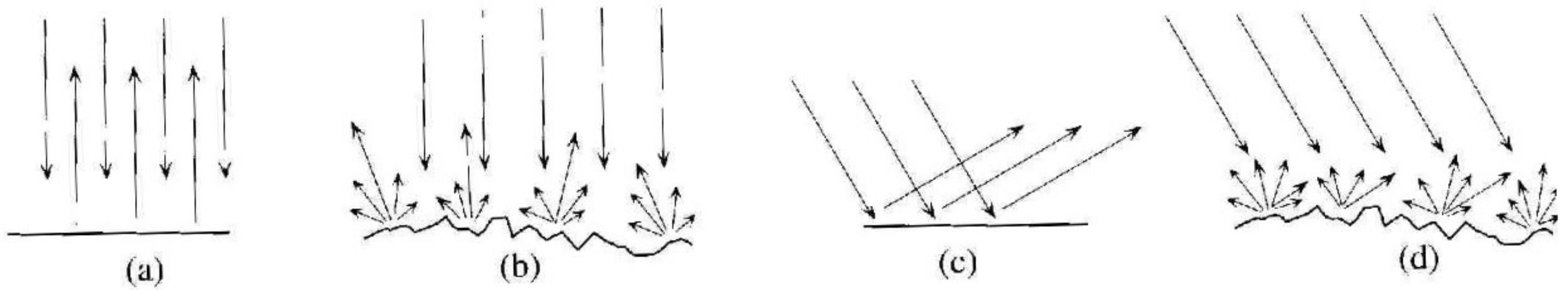
$\theta > 20°$ (occurs at all θ but dominates here)
off-nadir so polarization is important
Ocean wave-length of importance $L_B = \frac{\lambda}{2\sin\theta}$





σ_o depends on:

- Polarization
- Wavelength
- zenith angle
- wave spectrum (are there enough L_B's?) and wave spectrum in 2-D
projection of L_B fronts along line of sight



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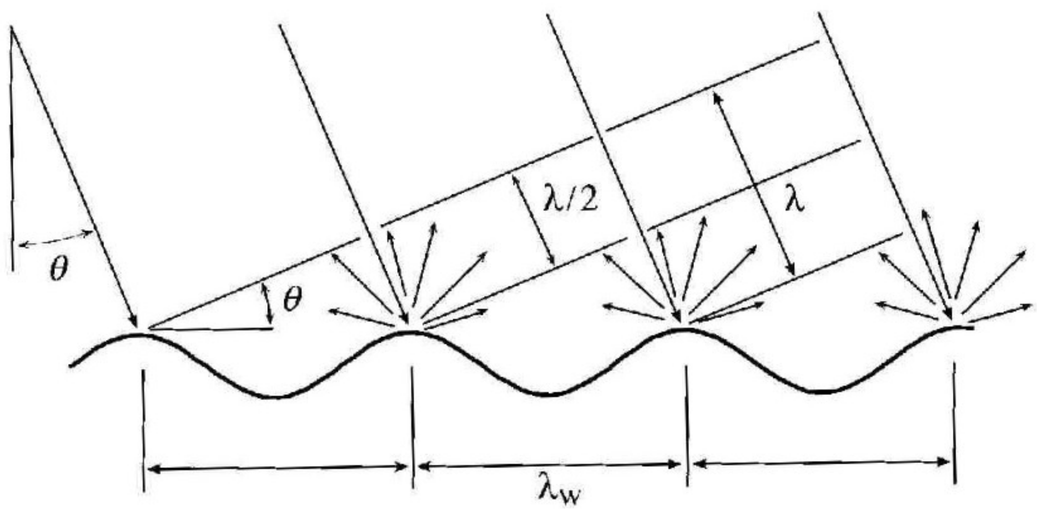

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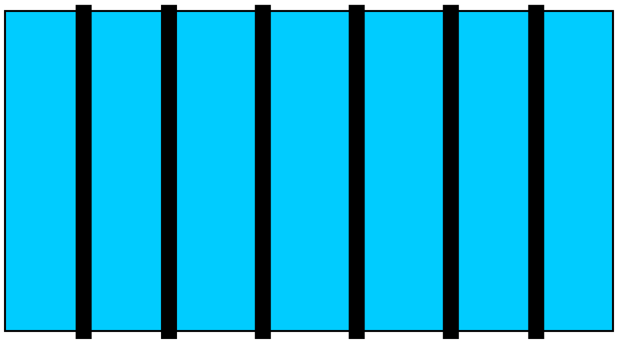
Backscatter Mechanism

- Assumed to be dominated by Bragg Scattering at incidence angles $\theta > 25^{o}$ from vertical
- Backscatter due to in-phase reflections from surface
- Constructive interference



- Bragg Scatter Equation:

$$\lambda_S = \frac{n\lambda_r}{2\sin\theta}$$

- the wavelength of the surface roughness (λ_s) that will give the maximum radar return for radar wavelength (λ_r)

  - For Ku band: $\lambda_S \sim 3$ cm (Seasat)
  - For C band: $\lambda_S \sim 6$ cm (ERS-1/2)

Factors Influencing Scattering

- Sea surface temperature
- Sea state
- Fetch
- Surface slicks (oil, biology)
- Rain
- Land

These factors can introduce large errors into scatterometer wind fields

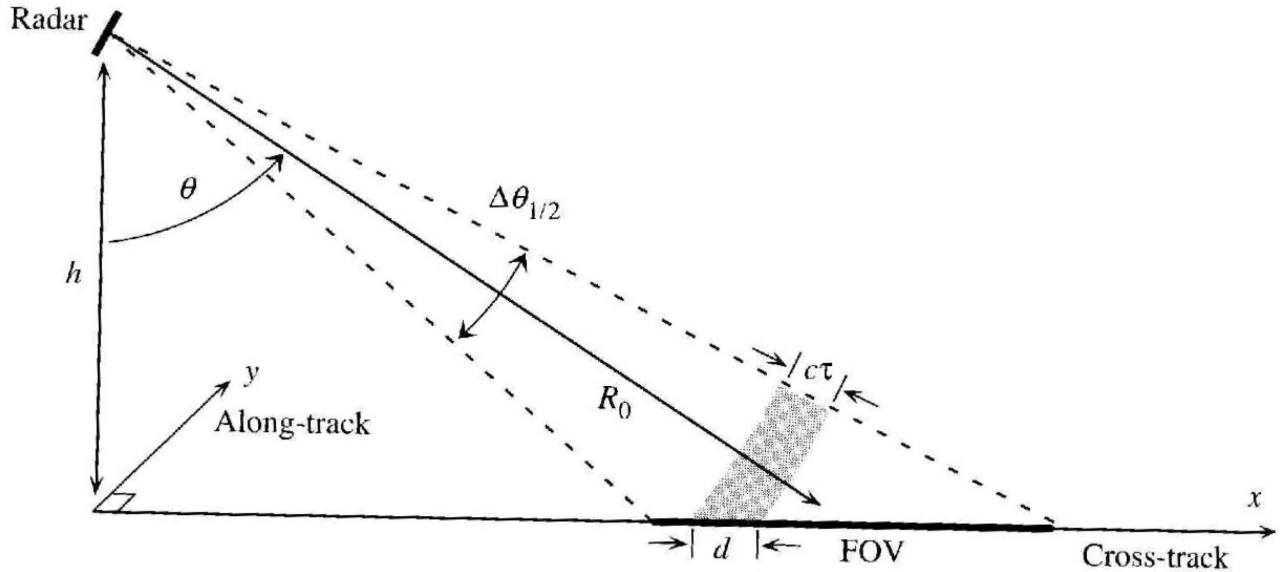


Figure 10.3. The interaction of a single pulse with the surface, where $c\tau$ is the pulse length and d is its projection on the surface.

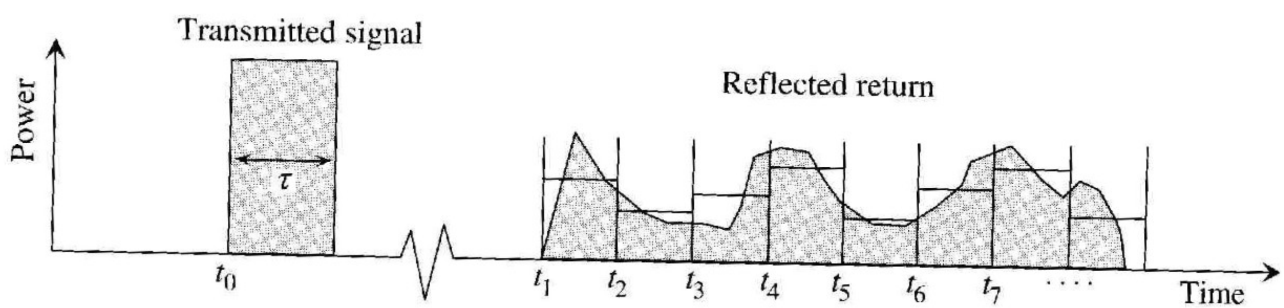


Figure 10.4. The binning of the radar return by time delay or range. The horizontal lines within each bin represent the average received power.

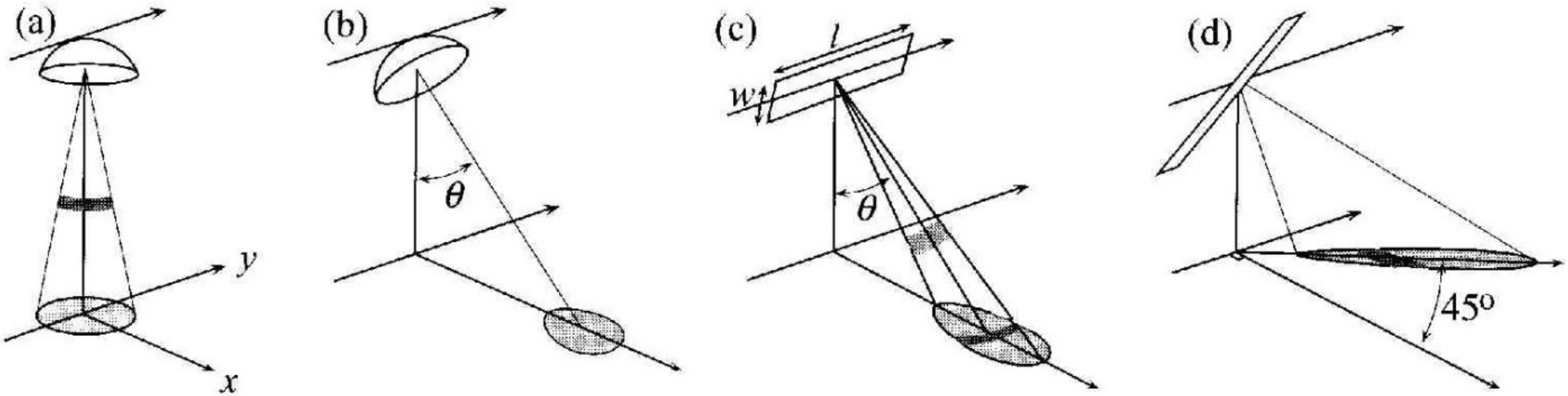


Figure 10.2. The configuration of four different antennas used in remote sensing. (a) The nadir-viewing altimeter parabolic antenna, (b) the side-looking parabolic antenna, (c) the side-looking rectangular antenna, (d) the scatterometer stick antenna, oriented at 45° to the flight path in a plane parallel to the surface. For each case, the light gray area on the surface is the FOV, while the dark gray swaths within the FOVs are in (c), a contour of constant range, and in (d), a contour of constant Doppler shift.

Active Microwave

Altimeters:

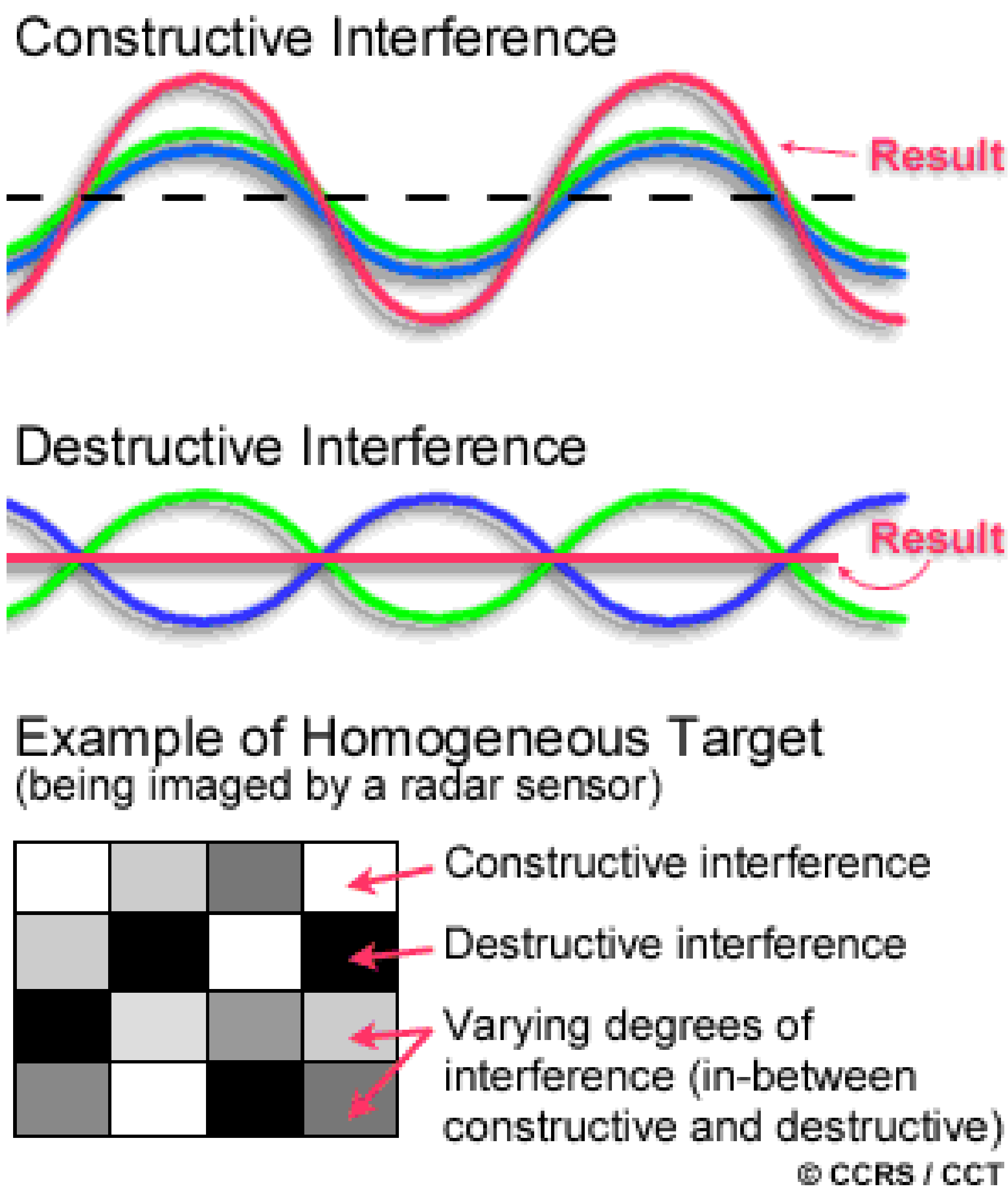
* Topex/Poseidon, 1992 -
* Jason-1, Dec. 7, 2001 -
* Geosat Follow On (GFO), U.S. Navy altimeter, February 1998 -
* ICESat or GLAS (the Geoscience Laser Altimeter System), 2003

Scatterometers:

* SeaWinds, (on QuikScat, 1999 - present; on ADEOS-2, launched Dec. 13, 2002)
* Envisat Scatterometer, March 2002 -

Synthetic Aperture Radars:

* Radarsat-1, 1995 -
* ERS-2 (European Remote Sensing Satellite 2) SAR, 1995 -
* Envisat ASAR, March 2002 -


Constructive Interference
Result
Destructive Interference
Result
Example of Homogeneous Target
(being imaged by a radar sensor)
Constructive interference
Destructive interference
Varying degrees of interference (in-between constructive and destructive)
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